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THE COMPRESSIBILITY OF NATURAL GAS AT HIGH PRESSURES

BY

G. A. BURRELL AND I. W. ROBERTSON

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THE COMPRESSIBILITY OF NATURAL GAS AT HIGH PRESSURES.

By G. A. BURRELL and I. W. ROBERTSON.

INTRODUCTION.

In the course of its examination of samples of natural gas from many different gas fields throughout the country the Bureau of Mines has conducted various special researches in order to ascertain with exactness the composition or physical properties of certain of the samples or to determine the bearing of the facts on larger problems involved in the transportation and use of the gas. This paper treats of an investigation of the compressibility, at pressures up to 35.5 atmospheres, of the natural gas supplied to the city of Pittsburgh and points out the bearing of the results on the measurement of natural gas at high pressures.

The compressibility of the different paraffin hydrocarbon gases that are found in natural gas and of samples of natural gas from different places in the United States will be shown in a subsequent publication.

COMPOSITION OF NATURAL GAS.

Analysis of the "dry" natural gas used at Pittsburgh by the fractionation method described in Technical Paper 104[a] gave the following results:

Composition of the natural gas of Pittsburgh.

Constituents.	Per cent.
Methane (CH_4)	84.7
Ethane (C_2H_6)	9.4
Propane (C_3H_8)	3.0
Butane (C_4H_{10}), chiefly	1.3
Nitrogen (N_2)	1.6
	100.0

The results are stated on the basis of water-free gas. The actual water-vapor content, by volume, of the samples the authors tested by passing them over phosphorus pentoxide was 0.7 per cent.

The natural gas used in Pittsburgh is typical of that supplied to many cities in Pennsylvania, Ohio, West Virginia, and other States, as

[a] Burrell, G. A., Seibert, F. M., and Robertson, I. W., Analysis of natural gas by fractional distillation at low temperatures and pressures: Tech. Paper 104, Bureau of Mines, 1915, pp. 8 to 20.

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is shown in the following table of analyses. Hence the authors believed that the determination of its compressibility would be of value for application to the measurement of a great deal of natural gas.

The compositions of the natural gas used in eight cities in the United States are as follows:

Composition of the natural gas from different cities.[a]

City.	CO_2.	CH_4.	C_2H_6.	N_2.	Total.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pittsburgh, Pa.	Trace.	79.2	19.6	1.2	100.00
Louisville, Ky.	...do.....	77.8	20.4	1.8	100.00
Buffalo, N. Y.	...do.....	79.9	15.2	4.9	100.00
Cincinnati, Ohio.	...do.....	79.8	19.5	.7	100.00
Cleveland, Ohio	...do.....	80.5	18.2	1.3	100.00
Springfield, Ohio	...do.....	80.3	14.7	5.0	100.00
Columbus, Ohio	...do.....	80.4	18.1	1.5	100.00
Chelsea, Okla.	...do.....	75.4	17.7	6.6	100.00

[a] Burrell, G. A., and Oberfell, G. G., The composition of the natural gas used in 25 cities: Tech. Paper 109, Bureau of Mines, 1915, p. 7.

These analyses were made by the ordinary combustion method and hence show only the two predominating paraffin hydrocarbons.[a]

COMPRESSIBILITY OF METHANE.

The compressibility of methane has been worked out by Amagat [b] for pressures from 39 atmospheres to 290 atmospheres. His results are shown in figure 2 (p. 9), in which the curve has been extrapolated from 39 atmospheres (his lowest observation) to 1 atmosphere. This extrapolation is merely approximate and the authors are now determining by experiment the actual compressibility of methane at pressures less than 39 atmospheres.

Methane is about 9 per cent more compressible at 40 atmospheres and about 17 per cent more compressible at 100 atmospheres than at 1 atmosphere. The compressibility of the other gaseous constituents of natural gas, such as ethane, propane, and butane, has not been determined. These constituents deviate more from Boyle's law than does methane, and hence make natural gas more compressible than if it consisted of methane alone.

EXPERIMENTS MADE.

DESCRIPTION OF APPARATUS.

The apparatus with which the authors performed their work is shown in figure 1, and was made at the Pittsburgh experiment station of the bureau by O. P. Hood, chief mechanical engineer, W. F. Haustein, instrument maker, and F. E. Donath, glass blower.

[a] See Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, p. 80.

[b] Landolt and Bornstein, Physikalisch-chemische Tabellen, 1905, p. 65.

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The reservoir *a* contains mercury, which can be forced into the tubes *c*, *d*, and *e* by screwing up the plunger *b*. One of the tubes *e*, served as a high-pressure, and another, *d*, as a low-pressure air

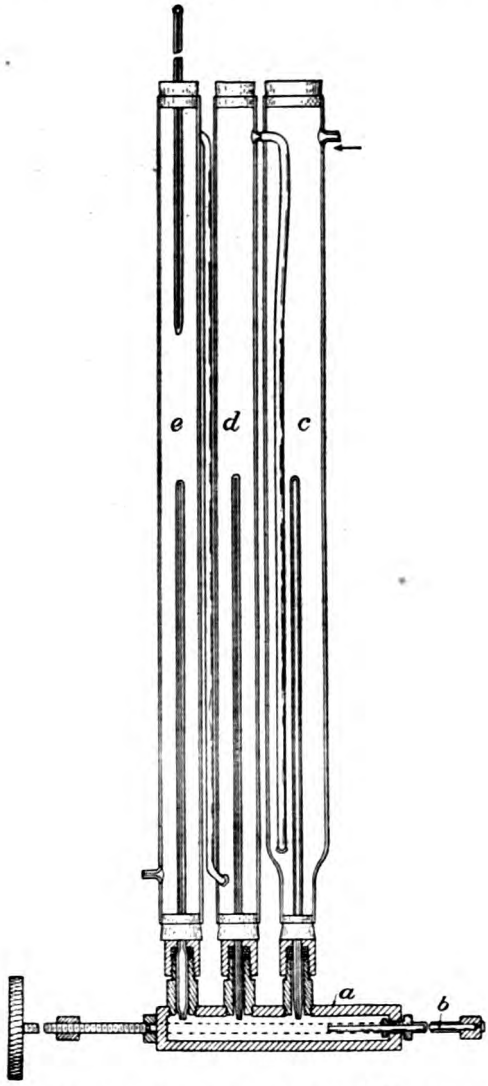

FIGURE 1.—Apparatus for determining compressibility of natural gas.

manometer. The tube *c* contained the natural gas, the compressibility of which was to be measured.

Each tube was calibrated by inserting in it a small thread of weighed mercury and forcing this along the entire graduated portion.

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The volume of this mercury having been calculated from the weight, the bore of the tube through its entire length was easily determined.

The two air manometers were calibrated to serve as pressure gages, the low-pressure manometer being calibrated against a long, open-tube manometer, and the high-pressure manometer against the low-pressure manometer.

COMPRESSIBILITY OF AIR.

The pressure-volume (PV) values for air with the high and low pressure manometers and with the gas manometer are shown in Table 1. In other words, PV for air was a constant within the error of experimentation, and within its determined deviation from Boyle's law. This provided a good check on the accuracy of the tube calibrations and pressure readings.

TABLE 1.—*PV values for air with different manometers.*

WITH GAS MANOMETER.

Volume.	Pressure.	PV.	Volume.	Pressure.	PV.
C. c.	*Mm. of mercury.*		*C. c.*	*Mm. of mercury.*	
0.4804	841	404.0	0.2312	1,737	401.6
.4743	852	404.1	.1888	2,128	401.8
.4676	865	404.5	.1504	2,678	402.8
.3882	1,041	403.8	.1167	3,442	401.7
.3358	1,195	401.3	.04812	8,334	401.0
.2853	1,416	403.9	.01251	32,153	402.2

WITH LOW-PRESSURE MANOMETER.

0.5119	857	438.7	0.3646	1,200	437.5
.5045	870	438.9	.3499	1,255	439.2
.4971	883	438.9	.3235	1,359	439.6
.4897	897	439.3	.3083	1,430	440.9
.4749	924	438.8	.2931	1,502	440.2
.4455	983	437.9	.2779	1,584	440.2
.4235	1,038	439.6	.2624	1,677	440.0
.3940	1,112	438.1	.2470	1,782	440.2
.3793	1,160	440.0	.2393	1,839	440.1

WITH HIGH-PRESSURE MANOMETER.

0.4784	2,035	973.6	0.3620	2,691	974.0
.4532	2,155	976.7	.3363	2,897	974.4
.4272	2,283	975.3	.3236	3,015	975.6
.4141	2,349	972.7	.3109	3,133	973.9
.4011	2,426	972.8	.2982	3,261	972.5
.3881	2,509	973.7	.2484	3,911	971.2

COMPRESSIBILITY OF NATURAL GAS USED IN PITTSBURGH.

Table 2 gives the PV products as determined for the natural gas of Pittsburgh, and shows that the gas is more compressible than an ideal gas. A correction has been applied for the compressibility of air.[a]

[a] Travers, M. W., The experimental study of gases, 1901, p. 167.

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TABLE 2.—*PV values for natural gas.*

Trial 1.								Trial 2.			
Volume.	Pressure.	PV (relative).	Correction.	Volume.	Pressure.	PV (relative).	Correction.	Volume.	Pressure.	PV (relative).	Correction.
C. c.	*Mm. of mercury.*		*Per cent.*	*C. c.*	*Mm. of mercury.*		*Per cent.*	*C. c.*	*Mm. of mercury.*		*Per cent.*
0.4801	893	428.7	99.9	0.02886	13,836	399.3	92.5	0.4821	892	429.6	99.9
.3509	1,220	428.1	99.8	.02634	15,078	397.2	92.0	.3228	1,329	429.0	99.8
.2823	1,506	425.1	99.2	.02372	16,557	392.7	90.8	.2154	1,966	423.5	98.6
.2013	2,098	422.3	98.4	.02111	18,353	387.4	89.6	.1936	2,184	422.8	98.3
.1532	2,749	421.1	98.1	.01983	19,416	385.0	88.9	.1536	2,741	421.0	97.7
.1150	3,642	418.8	97.5	.01852	20,605	381.6	88.2	.1153	3,638	419.5	97.4
.09143	4,569	417.7	97.2	.01719	21,969	377.6	87.2	.06252	6,633	410.6	95.4
.07554	5,510	416.2	96.9	.01601	23,466	375.6	86.6	.04678	8,763	409.9	95.0
.05961	6,938	413.6	96.2	.01470	25,346	372.3	85.7	.02378	16,513	392.7	90.7
.04665	8,785	409.8	95.1	.01345	27,467	369.4	85.0	.01854	20,540	380.8	87.7
.03924	10,428	409.2	94.9	.....	.....	.....	.....	.01611	23,450	377.8	86.8
.03398	11,891	404.0	93.7	.....	.....	.....	.....	.01356	27,390	371.4	85.2

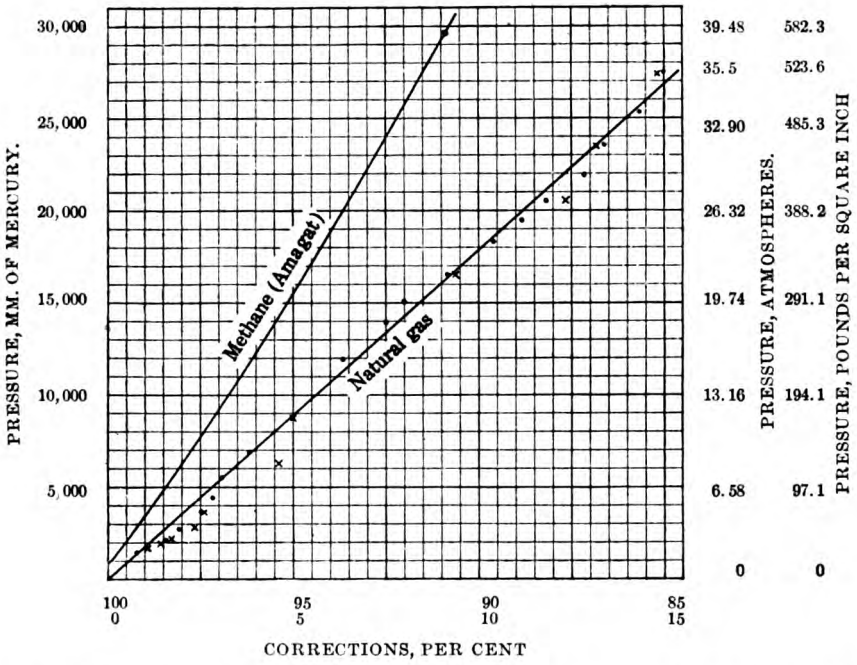

FIGURE 2. Compressibility of the natural gas of Pittsburgh, and of methane. Methane curve plotted from results of experiments by Amagat.

The results given in Table 2 are plotted in figure 2. The curve shows the greater compressibility of the natural gas at different pressures, as compared with an ideal gas.

As to the application of these results, the reader should note that sometimes natural gas is measured at pressures as high as 40 atmospheres (about 600 pounds per square inch) and that many millions of

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cubic feet are measured at pressures of 20 to 30 atmospheres (300 to 450 pounds per square inch). In computing the volume of gas the assumption is always made that Boyle's law applies; that is, that the product of pressure and volume is a constant at all pressures. Hence in measurements under high pressure the error introduced is of great magnitude. For instance, suppose 100,000,000 cubic feet of gas a day is measured at 375 pounds pressure (25.6 atmospheres). According to figure 2, the gas is 11 per cent more compressible at 375 pounds (25.6 atmospheres) than at atmospheric pressure. This means that each day 11,000,000 more cubic feet of gas is measured than is supposed. If no correction is applied in measuring the gas, a distributing company that buys natural gas at high pressure and sells it at low pressure may sell much more gas than it pays for.

SUMMARY.

The compressibility of the natural gas of Pittsburgh differs from that of an ideal gas, the deviation amounting to as much as 15 per cent at a pressure of 35.5 atmospheres. The results are of practical value, because in measuring natural gas it is the practice to assume that the product of the pressure by the volume is a constant.

ACKNOWLEDGMENTS.

The authors are indebted to Dr. G. A. Hulett, consulting chemist, and F. M. Seibert, assistant chemist, of the Bureau of Mines, for valuable assistance in conducting this work. The results and their application have been discussed with S. Wyer, consulting engineer, Columbus, Ohio, who is working on the same problem.

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